

Direct photon production at RHIC

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Abstract. Direct photon in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV has been measured by the PHENIX experiment at RHIC, and we report recent results. Direct photons are produced in the initial hard partonic scatterings, are not affected by the strong interaction, and can be described by perturbative QCD. Consequently, they are offer a powerful probe of the nature of the produced medium. We have reported that the nuclear modification factor R_{AA} of direct photon is one at high- p_T region of the above 5 GeV/c [1]. This fact means that the number of scaling works well at high p_T , and it indicates that high- p_T direct photon is hard-scattering dominant.

At low- p_T region of $1 < p_T < 3$ GeV/c, the yield of direct photon has been measured with internal conversion method recently. At low p_T , the large excess of direct photon yield is observed, and the excess of the yield is larger than that in d +Au collisions. Furthermore, we have been measured the azimuthal anisotropy v_2 of direct photons, which can provide a glimpse of the early space-time evolution in the collision. The result of our measurement clearly shows that the v_2 of direct photon has positive value at low p_T , while it is zero at high p_T .

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SPECTRA OF DIRECT PHOTON

At low p_T range of $1 < p_T < 3$ GeV/c, it is predicted that the photon yield is enhanced by thermal radiation from hadron and Quark Gluon Plasma (QGP) phases [2]. Therefore, the measurement of direct photon include the fruitful information from QGP phase. However, the measurement is of great difficulty due to the huge background from hadron decay products, and they are detected from all stages changing in space-time evolution after the collision.

The low- p_T direct photon has been measured with virtual photons, which convert to low-mass e^+e^- pairs. Since any source of high energy photons can generally emit virtual photon, we just have to measure “quasi-real” virtual photon with internal conversion method.

The left panel of Fig. 1 shows the direct photon spectra in Au+Au collisions (closed red points) with the previously measured direct photon data (open blue points) from Ref. [3, 4] and NLO pQCD calculations [5]. The right panel of Fig. 1 shows the direct photon spectra in d +Au collisions (open and close red points), Au+Au collisions (blue points), $p + p$ fit curve (dashed line) multiplied by the Glauber nuclear overlap function T_{AA} . The $p + p$ data are shown as an invariant cross section using $d\sigma = \sigma_{pp}^{ine} dN$, where σ_{pp}^{ine} is the inelastic cross section in $p + p$ collisions.

The pQCD calculation is consistent with the $p + p$ data within the theoretical uncertainties for $p_T > 2$ GeV/c. The $p + p$ data can be described by a modified power-law function, $A_{pp}(1 + p_T^2/b)^{-n}$, as shown by the dashed curve in the left panel of Fig. 1. The spectra in Au+Au collisions are above the $p + p$ fit curve scaled by T_{AA} for $p_T < 2.5$ GeV/c. It indicates that the direct photon yield at low- p_T in Au+Au collisions is larger than the binary NN collision scaled $p + p$ cross section, while the excess in d +Au collisions from the scaled $p + p$ fit curve is small. Therefore, the excess in Au+Au collisions is not due to the initial state effect as Cronin effect or nuclear shadowing. Additionally, the yields of direct photon at high- p_T measured at PHENIX and STAR are compared, and both results are consistent within the uncertainties [6].

We fit an exponential plus the T_{AA} -scaled $p + p$ fit function ($Ae^{-p_T/T} + T_{AA} \times A_{pp}(1 + p_T^2/b)^{-n}$) to the Au+Au data. The free parameters in the fit are A and the inverse slope T of the exponential term. The results of the fits are summarized in Table 1, where A is converted to dN/dy for $p_T > 1$ GeV/c. The obtained inverse slope T has small centrality dependence. The more central collision is, the larger the inverse slope is.

If the direct photons in Au+Au collisions are of thermal origin, the inverse slope T is related to the initial temperature T_{init} of the dense matter. Several hydrodynamical models can reproduce the central Au+Au data within a factor of 2. For the comparison of hydrodynamical models with different assumptions, the initial temperature T_{init} is estimated to be 300–600 MeV, and this temperature is above the critical temperature (~ 170 MeV) expected from lattice QCD calculation. It should be noted that the initial temperature strongly depends on the thermalization time τ_0 ranging from

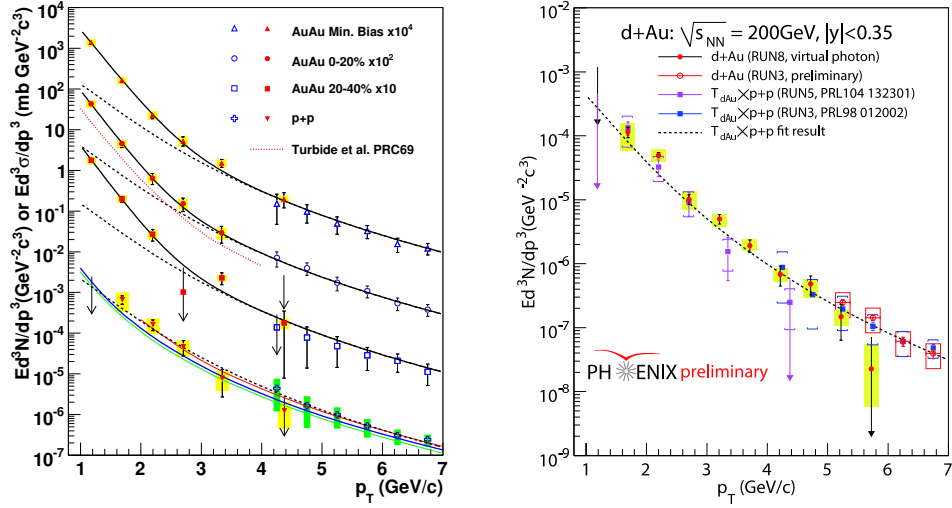


FIGURE 1. Left: Invariant cross section ($p + p$) and invariant yield (Au+Au) of direct photons as a function of p_T [9]. Right: Invariant yields in $d + \text{Au}$ collisions, and the scaled $p + p$ fit curve as a function p_T .

0.15 to 0.6 fm/c. Therefore, we need to constrain the thermalization time to measure the initial temperature more precisely.

TABLE 1. The inverse slope T in Au+Au collisions obtained from the fit as a function of centrality class.

Centrality	dN/dy ($p_T > 1$ GeV/c)	T (MeV)	χ^2/DOF
0-20 %	$1.50 \pm 0.23 \pm 0.35$	$221 \pm 19 \pm 19$	4.7/4
20-40 %	$0.65 \pm 0.08 \pm 0.15$	$217 \pm 18 \pm 16$	5.0/3
Min. Bias	$0.49 \pm 0.05 \pm 0.11$	$233 \pm 14 \pm 19$	3.2/4

AZIMUTHAL ANISOTROPY OF DIRECT PHOTON

If the source of photon is of thermal origin, the azimuthal anisotropy of thermal photon in quark matter is expected to be positive at low p_T , while it is expected to zero at high p_T [7]. It is predicted that the smaller the azimuthal anisotropy is, the earlier the thermalization time τ_0 is. Therefore, the measurement of the azimuthal anisotropy enables us to constrain τ_0 .

The azimuthal anisotropy v_2 with respect to the reaction plane has been measured for direct photons at mid-rapidity and p_T range of 1–15 GeV/c in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV [8]. Previous measurements of the azimuthal anisotropy v_2 for hadrons with $p_T < 6$ GeV/c indicate that the medium behaves as a nearly perfect fluid, while the azimuthal anisotropy v_2 for $p_T > 6$ GeV/c is thought to be the consequence of path-length dependence for parton energy loss.

Figure 2 shows the azimuthal anisotropy v_2 of direct photon for different centrality classes as a function of p_T . We used two independent detectors, BBC and RxNP, to determine the reaction plane. At low- p_T region of the below 3 GeV/c, each azimuthal anisotropy v_2 is consistent within the uncertainties. The obtained azimuthal anisotropy is significantly positive at low p_T , and it remains inconclusive for the centrality dependence. At high- p_T region, the azimuthal anisotropy v_2 with BBC agrees with that with RxNP. It rapidly goes to zero at the p_T range of 5–6 GeV/c independently of the centrality class. Therefore, direct photon at high p_T is thought to be produced by the hard scatterings at early stage of collisions. This interpretation is consistent with the fact that the nuclear modification factor (R_{AA}) of direct photon is one at high p_T .

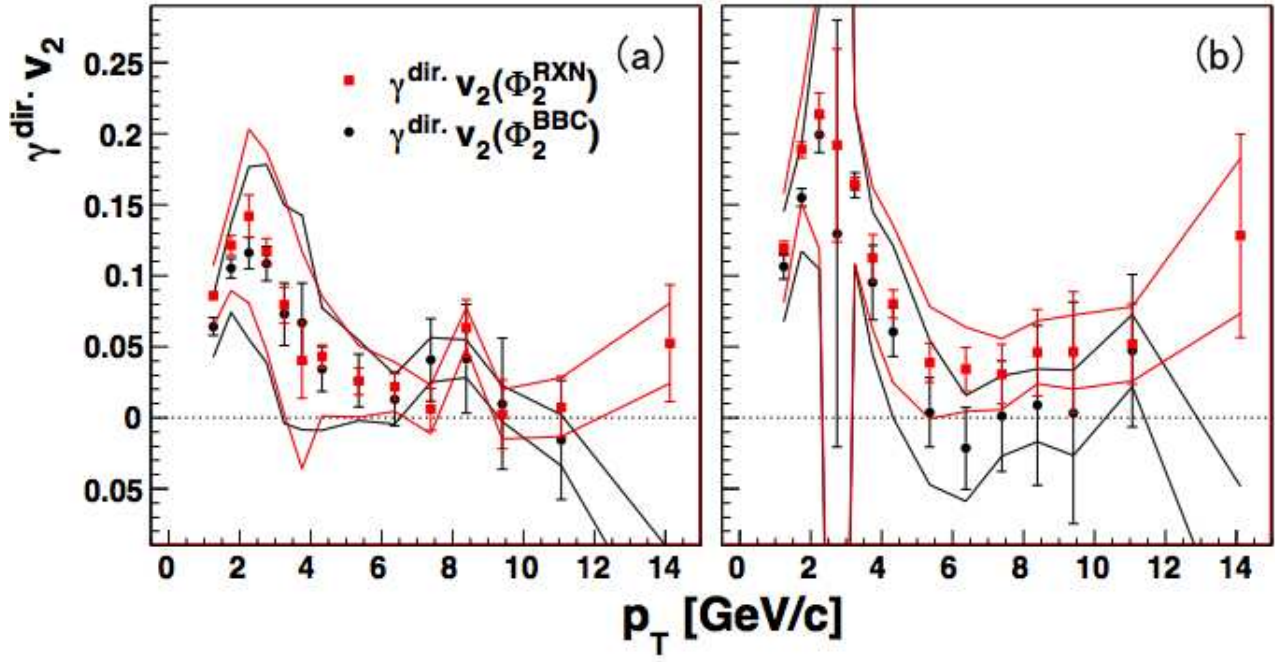


FIGURE 2. Centrality dependence of the direct photon v_2 . (a) the centrality class is 0–20 %, (b) the centrality class is 20–40 %. Red squares and black circles are the azimuthal anisotropy v_2 of direct photon with RxNP and BBC, respectively. The bars and bands around the data points are statistical and systematic uncertainties, respectively. The direct photon fraction is taken from Ref. [9] up to p_T range of 4 GeV/c and from Ref. [3] for higher p_T region.

Qualitatively, it agrees with the prediction assuming very early thermalization time in Ref. [7]. However, we need to reduce the measurement uncertainties to discuss about the thermalization time more quantitatively. It should be also noted that v_2 with RxNP at centrality 20–40 % is consistently higher than that with BBC due to the increased bias from non-flow correlations in determining the reaction plane with RxNP. The azimuthal anisotropy v_2 of direct photon measured at PHENIX is compared to that at STAR [10], and these results are consistent within the uncertainties at high- p_T region.

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